10.0 RI CONCEPTUAL SITE MODEL FOR SELECT INDICATOR CHEMICALS

The CSM for the Portland Harbor Study Area is presented in this section. A CSM is a representation of an environmental system and the biological, physical, and chemical processes that affect the transport of contaminants from sources through environmental media to human and ecological receptors in the system. CSMs are a critical component of the RI/FS process because they establish the link between investigation data and the assessment of risk (ASTM 1995).

This section presents a CSM for the Portland Harbor RI/FS Site that draws on and synthesizes supporting information presented previously in this RI Report or in associated RI/FS documents. Section 10.1 presents a Study Area-wide overview of the physical setting; contaminant distribution in sediments; contamination sources identified to date; external loading and internal fate and transport mechanisms; and human health and ecological receptor risk drivers and exposure pathways/scenarios (USEPA 2005a).

Section 10.2 is a CSM presentation for the specific indicator contaminants~~ICs~~ described in Section 5, consistent with EPA (2005a) guidance. It includes a series of contaminant-specific maps of the Study Area's abiotic and biotic data sets that illustrate relationships between the observed contaminant distributions and known and likely historical and current sources and pathways. These displays are intended to provide a picture of the distribution, transport, and fate of contaminants in the Study Area across a range of physical, chemical, and biological processes, as well as potential sources.

PCBs are the most widespread organic contaminant group in the Study Area and present the most significant risk to human health. TCDD/F, total DDx, and total PAHs also are widespread throughout the Study Area, and in most cases, the distribution of these contaminants, together with PCBs, create the outer boundaries of potentially unacceptable contaminant-related human health and environmental risk in Portland Harbor.

The general objective of this CSM is to illustrate our understanding of the sources and fate and transport mechanisms that determine the observed distribution of individual contaminants in affected abiotic and biotic media across the Study Area, based on the information and data collected, compiled, and evaluated in this RI.

10.1 SITE CONCEPTUALIZATION

A pictorial representation illustrating the major elements of the CSM (sources, pathways, fate and transport mechanisms, and human and ecological receptors) for the Portland Harbor Study Area is shown in Figure 10.1-1, while Figure 10.1-2 presents a graphical conceptualization of the sources, release mechanisms, transport media, and exposure media of the CSM. The detailed human health and ecological CSMs for the Portland Harbor Site are summarized in Appendix F, Figure 3-1 (also RI Section 8,

Figure 8.2-1) and Appendix G, Attachment 2, Figure 1 (also RI Section 9, Figure 9.1), respectively, and focus on exposure routes and receptor groups.

~~In its natural, undisturbed state, the Study Area reach was a relatively shallow, meandering portion of the LWR, surrounded by uplands, forested wetlands, and floodplains. Much of the original riverbank has been filled, stabilized, and/or engineered for commercial, industrial, and marine operations with riprap, bulkheads, and overwater piers and docks. The extensive physical alteration and the associated anthropogenic activities as well as upstream river-stage control through the construction and management of dams, have resulted in a river reach that little resembles its pre-industrialized character in terms of hydrodynamics, sediment processes, and ecological habitat.~~

Commented [Int1]: Moved this EPA retained text to the next paragraph

~~10.1.2~~10.1.1 Physical Setting and Sediment Dynamics~~Flow Regime, Hydrodynamics, and Sedimentation~~

The Portland Harbor RI/FS Study Area (RM 1.9 to 11.8 of the Willamette River) is located at the downstream end of the LWR, which extends from the Willamette Falls at RM 26 to its convergence with Columbia River at RM 0. In its natural, undisturbed state, the Study Area reach was a relatively shallow, meandering portion of the LWR, surrounded by uplands, forested wetlands, and floodplains. Over the last century, much of the original riverbed has been dredged and the adjacent riverbanks have been filled, stabilized, and/or engineered for commercial, industrial, and marine operations with riprap, bulkheads, and overwater piers and docks. The extensive physical alteration and the associated anthropogenic activities as well as upstream river-stage control through the construction and management of dams, have resulted in a river reach that little resembles its pre-industrialized character in terms of hydrodynamics, sediment processes, and ecological habitat.

Today, t~~T~~he Study Area is a relatively low-energy, depositional reach of the LWR. The LWR upriver of the Study Area ~~upstream portion~~ is markedly narrower, ~~and~~ more confined by bedrock outcrops, and faster flowing than the Portland Harbor reach. Immediately downstream of the Study Area, the river narrows as it turns and converges with the Columbia. Multnomah Channel exits at RM 3, considerably reducing discharge downstream of that point. This physical setting and the associated hydrodynamic interactions result in deposition and accumulation of sediments entering the harbor from lateral sources, as well as a good portion ~~some~~ of the suspended, and most of the bedload, sediments ~~that~~ entering the Study Area from upstream over time. Most of the organic contaminants (e.g., PCBs, dioxins, pesticides, and PAHs) in Portland Harbor are hydrophobic chemicals that are strongly associated with the organic fractions of sediment particles, in particular cohesive or fine-grained particles (silts and clays). The inorganic contaminants, (e.g., As, Cu, and Zn) are also typically strongly associated with fine-grained sediments through adsorption. As a result, the physical transport and fate of sediments in the Study Area, especially silts and clays, strongly affects the distribution of most contaminants.

Within the Study Area, there are distinct reaches that share similar hydrodynamic and sediment bed characteristics (see Section 3.1.5). The primary factors controlling river flow dynamics, sediment deposition and erosion, and riverbed character appear to be the river cross-sectional area and navigation channel width.

Long-term net sedimentation rates were estimated for subsections of the Study Area based on time-series bathymetric surveys. Map 3.1-7 shows the measured riverbed elevation changes over the seven-year period from 2002 to 2009 and illustrates a pattern of general shoaling in the relatively wide reaches from RM 7 to 10 and RM 2 to 5 and no change or scour in the higher energy, narrow reaches upstream of RM 10 and between RM 5 and 7. The maximum net sedimentation accumulation occurs in the navigation channel between RM 9 and 10 and in the upstream borrow pits at RM 10.9 and 10.5. Maximum sedimentation rates over the seven-year period approach and, in some places, exceed 30 cm/yr in these areas.

Shoaling on a similar scale along the western half of the navigation channel, from RM 8 to 10, is evident from the 2002 to 2009 bathymetric change data set (e.g., a maximum accumulation rate of 31 cm/yr on the shoal at RM 9.6); this area has historically required regular maintenance dredging. Bathymetric change data from 2002 to 2009 in the downstream channel shoaling area, which begins at RM 2.8 and extends downstream towards the confluence with the Columbia River, showed a maximum sediment rate of about 18 cm/yr at RM 2 over this seven-year time frame. The decrease in net sedimentation rates between upstream and downstream channel shoaling areas is consistent with a single major source of sediments (both suspended sediments and bedload sediments) that enter the Study Area from upstream and then settle out or are trapped in depressions and shoaling areas from upstream to downstream.

Estimates of net sedimentation rates for nearshore (i.e., shoreward of the federal navigation channel and off-channel areas in the Study Area [e.g., Swan Island Lagoon] are based on bathymetric change data, SPI observations (SEA 2002b), and the radioisotope sampling for MNR assessment (Anchor 2005). These data indicate that sediments do not generally accumulate in nearshore areas at the rates noted above for the major shoals in the main channel environment. Nonetheless, many nearshore areas exhibit fine-grained sediments and are depositional (e.g., based on SPI interpretation). Based on the bathymetric change data (Map 3.1-7), some of these off-channel areas (e.g., RM 2-3W, RM 4-, 5, RM 7-8, RM 8-9W) show net sediment accumulation exceeding 30 cm from 2002 to 2009. In other areas, such as RM 9-11E, areas within Swan Island Lagoon and Willamette Cove, RM 6-7W, and RM 5-7E, little net elevation change and/or small-scale scour was observed. Net sedimentation rates of approximately 1 cm/yr were calculated from radioisotope data collected in 2004 from four nearshore areas in water depths of –4 to –28 ft NAVD88, these areas showed well-mixed surface sediment layers.

In summary, most of the Portland Harbor channel and off-channel areas appear to either accumulate sediment or show minimal change over time. While most nearshore areas appear to be stable/depositional environments, some areas are subject to disturbance and sediment resuspension. Net sedimentation rates in nearshore areas appear range from relatively low (i.e., ≤ 1 cm/yr) to greater than 5 cm/yr. The revised FS HST model suggests that during extreme events, such as the 1996 flood, relatively deep (1-2 meters) scour occurs only in the sandier, high-energy, in-channel reaches. The remainder of the Study Area is predicted to remain stable or accumulate sediments during these events.

~~10.1.3~~10.1.2 ~~Overview of~~ Contaminant Distribution

This section provides a brief overview of the overall distribution of contaminants ~~ICs~~ in ~~the~~ Study Area sediments, the CSM data presentations that follow in Section 10.2 focus on the distributions of individual indicator contaminants~~ICs~~ separately. Contaminant concentrations in sediment and other media are presented in Panels 10.2-1 through 10.2-15. Sediment concentrations are grouped into concentration ranges based on the data distributions (see Section 5.1.3) and are presented in Thiessen polygons. Based on examination of the contaminant distribution trends some general patterns emerge among subsets of different contaminants~~ICs~~ that reflect ~~may be indicative of~~ Study Area fate and transport processes, as well as the relative importance of regional (e.g., upstream) versus Study Area sources. These general patterns are discussed below.

Sediment contaminant concentrations are greatest in nearshore areas: concentrations of anthropogenic organic contaminants are generally higher in localized nearshore and off-channel areas as compared to sediments in the navigation channel, Multnomah Channel, and downstream areas. In contrast, metals generally exhibit a much narrower concentration range throughout the LWR than the organic compounds.

Contaminant concentrations are generally greater in subsurface sediments: concentrations of organic contaminants ~~also~~ tend to be higher in subsurface sediments than in surface sediments. The concentrations of total PCBs, total DDx, total PAHs, hexachlorobenzene, total chlordanes, aldrin and dieldrin, gamma-hexachlorocyclohexane (Lindane), lead, and TBT are higher in subsurface sediments than in surface sediments, indicating that historical inputs were likely greater than current inputs. In contrast, arsenic, copper, chromium, mercury, and zinc do not have large concentration ranges and generally show similar levels in surface and subsurface sediments.

Commented [Int2]: Some non-IC contaminants were added to these lists per discussion w/EPA on 12/1

Regional inputs exhibit uniform concentrations across the area: Contaminants that may be derived predominantly from regional or upstream inputs show widespread surface sediment distributions without distinct, isolated elevated areas. Examples of this are arsenic~~, and~~ chromium (Panels 10.2-9A–B and 10.2-12A–B), and mercury (Appendix D1.2-46 and D1.2-47) which occur at relatively low concentrations throughout the Study Area, and no strong concentration gradients are apparent.

Areas of high concentrations are present throughout the Study Area and generally are associated with known upland sources: A number of ~~ICs~~contaminants exhibit relatively high sediment concentrations in distinct areas offshore of known or likely sources. These areas are separated by large areas with relatively lower concentrations lacking obvious concentration gradients. ~~ICs~~ Contaminants that exhibit this general trend include total PCBs, TCDD, BEHP, butylbenzyl phthalate, pentachlorophenol, hexachlorobenzene, total chlordanes, gamma-hexachlorocyclohexane, copper, zinc, and TBT.

Areas of high concentrations are more common in the lower (downstream) half of the Study Area: Two contaminants, total DDx and total PAHs, exhibit elevated concentrations at locations in the center of the Study Area adjacent to known upland sources. Ambient concentrations of these contaminants downstream of these areas are elevated relative to upstream concentrations.

Concentrations of certain metals are correlated to sediment grain size: A comparison of metals concentrations to the distributions of percent fines in the Study Area shows that where sediments are comprised of less than 40 percent fines, chromium and copper concentrations are relatively low (i.e., above RM 10, between RM 5 and 7, and in the Multnomah Channel; compare Map 3.1-2 with Panels 10.2-12A and 10.2-10A). A similar, but less pronounced, correspondence exists between sandy sediments and zinc concentrations (Panel 10.2-11A).

Multiple contaminants co-occur~~ore than one contaminant is typically observed in more contaminated areas~~: Several locations within the Study Area have relatively high surface sediment concentrations of more than one contaminant~~IC~~. These areas and the co-occurring contaminants are as follows:

- **RM 9.7W:** total PCBs, dioxins/furans, BEHP, zinc
- **RM 8.7–9.3W:** total PCBs, dioxin/furans, total PAHs, total chlordanes, copper, mercury, nickel, zinc
- **RM 8.3W:** total PCBs, total PAHs, BEHP, total chlordanes, dieldrin, lead, copper
- **Swan Island Lagoon:** total PCBs, dioxins/furans, total PAHs, BEHP, total chlordanes, copper, zinc, chromium, TBT
- **RM 6.8–7.5W:** dioxins/furans, total DDx
- **RM 6.7–6.8E:** total PCBs, dioxins/furans, copper
- **RM 5.6–5.7E:** dioxins/furans, total PAHs, total chlordanes, gamma-hexachlorocyclohexane, copper, lead, mercury, zinc, chromium
- **RM 4.3–4.5E:** total PCBs, dioxins/furans, total PAHs, total chlordanes, zinc
- **International Slip:** total PCBs, dioxins/furans, total PAHs, BEHP, total chlordanes, copper, lead, zinc, chromium, TBT.

This degree of contaminant co-occurrence in specific Study Area locations reflects the history of upland site development, including waste and stormwater conveyance systems and industrial and commercial activities, as described in Section 3 and summarized in Section 10.1.3 below.

~~10.1.4~~10.1.3 Site Sources

The following is a summary of information presented in Section 4 on the general nature of historical and current sources and associated pathways to the Study Area.[1]

~~10.1.4.1~~10.1.3.1 Historical

Historical sources dating back to the early 1900s contributed to the majority of the observed contaminant distributions in sediments within the Study Area. This is reflected in the extent and degree of subsurface sediment contamination as discussed in the previous section. Nearly all the identified chemical pathways have an historical component.

In the early 1900s, rivers in the United States were generally used as open sewers, which was also true for the Willamette (Carter 2006). Untreated sewage, contaminated stormwater runoff from various land uses, as well as process water from a variety of industries, including slaughterhouses, lumber mills, paper mills, and food processors, was discharged directly into the river, as were pollutants from less conspicuous (non-point) sources, including agricultural fields, oil spills, rubber and oils, and garbage dumps. With the general exception of manufactured gas operations and bulk fuel storage, which began in the late 1800s, most chemical manufacturing and use began in the 1930s.

Commented [Int3]: These details are important for historical context.

Commercial and industrial development in Portland Harbor accelerated prior to World War I and again during World War II. These industrial operations and their associated COIs are discussed in more detail in Section 3 and summarized here:

- **Ship Building, Dismantling, and Repair.** VOCs, SVOCs, PAHs, PCBs, TPH, copper, zinc, chromium, lead, mercury, phthalates, and butyltins are common sediment contaminants associated with shipyards. Approximate areas of former shipyards include RM 4E, 5.6E, 7E, 7.4E, Swan Island, RM 9W, 10W, and 11E. Ship building continues at a much smaller scale in Portland Harbor today, with most work focused on ship maintenance and repair.
- **Wood Products and Wood Treating.** COIs typically associated with sawmills include metals, TPH, and PAHs. In addition to these COIs, plywood

[1] *The source information presented in this Portland Harbor RI report is a compilation of public information available from site owners and operators and from DEQ, and is based upon information provided through September 2010, and DEQ's September 2010 Source Control Milestone Report. Source information will be updated in the Portland Harbor FS report. For the most up-to-date DEQ source information, DEQ's November 2014 Source Control Milestone Report is available online at http://www.deq.state.or.us/lq/cu/nwr/portlandharbor/report.html*

manufacturing could include VOCs and SVOCs, as well as possibly pesticides and fungicides (Eaton et al. 1949; U.S. Forest Service 1964; Moore and Loper 1980; Stellman 1998). Lumber mills and wood treatment facilities operated at various locations within the Study Area historically. McCormick& Baxter, a large wood-treating facility, existed at RM 6.9–7.2E. COIs associated with wood treatment include creosote/diesel oil mixtures, PCP, and a variety of water- and ammonia-based solutions containing arsenic, chromium, copper, and zinc (EPA 2006d). PCP wood treatment products routinely contain dioxin/furans as contaminants, and these are an additional COI of wood treatment facilities (EPA 2004b). Many other lumber mills and plywood manufacturers were found throughout the Study Area, including Linnton Plywood, St. Johns Lumber (which operated on the present-day Crawford Street and BES WPCL sites), Kingston Lumber, and former mills in Willamette Cove.

- **Chemical Manufacturing and Distribution.** Study Area chemical plants (RM 6.8–7.5W) that manufacture pesticides and herbicides were in place as early as 1941. COIs typically associated with these operations include pesticides, herbicides, VOCs, dioxins/furans, and metals.
- **Metal Recycling, Production and Fabrication.** Metal salvage and recycling facilities operated at RM 4E, 5.8W, 7.3W (Schnitzer-Doane Lake), 8.5W (Calbag/Acme), 8.9W (Gunderson – Former Schnitzer Steel auto dismantling), and 10W (Calbag) in the Study Area, and several scattered locations upriver COIs commonly found in waste streams from metal recycling facilities include VOCs, TPH, PCBs, phthalates, cyanide, and a variety of metals. Metal production and fabrication, currently takes place in the Burgard Industrial Park and several sites in the RM 8 to 10.3W reach. COIs associated with metal production and fabrication include metals, PAHs, and TPH. Hydraulic oil with PCBs was often used for high-temperature applications such as die-casting machines.~~,~~ Metal plating also has occurred at a few locations in the Study Area, including Columbia American Plating at RM 9.5W. COIs associated with metal plating activities include VOCs, PAHs, TPH, cyanide, and several metals.
- **Manufactured Gas Production.** Manufactured gas production operations took place between 1913 and 1956 at Portland Gas & Coke (RM 6.2W). The Pintsch Compressing Company Gas Works at RM 7.3W operated between 1890 and the mid-1930s and manufactured compressed gas from crude oil for railroad train lighting. Prior to 1913, gas production also occurred just upstream of the Study Area at the Portland MGP site at RM 12.2E. COIs associated with manufactured gas operations include VOCs, SVOCs, TPH, PAHs, metals, and cyanide.
- **Electrical Production and Distribution.** Electrical transformers and capacitors are associated with all of the major industries in the harbor. Some of these transformers and capacitors may contain PCBs. Seven current and one historical substation are found in the Study Area. Transformer repair, servicing, and salvaging operations were found on the east bank from RM 11.3 to 11.5 (Tucker

Building, Westinghouse, and PacifiCorp Albina Properties), at RM 3.7W (ACF Industries), RM 9.5E (Portable Equipment Salvage), RM 9.5W (GE Decommissioning), and the GE facility at NW 28th Ave (TSCA site). COIs linked with these types of operations include PAHs, TPH, and PCBs.

- **Bulk Fuel Distribution and Storage and Asphalt Manufacturing.** Bulk fuel facilities have a long history in Portland Harbor. By 1936, most of the facilities currently in place had been established between RM 4 and 8 on the west side of the river. COIs typically associated with bulk fuel storage operations include VOCs, SVOCs, PAHs, TPH, and metals.
- **Steel Mills, Smelters, and Foundries.** The harbor hosted several foundries at RM 11.4W (Gender Machine Works), at RM 9.7W (Schmitt Forge), and at RM 2.7E (Consolidated Metco). Several smelters were located at RM 7.2W (Gould), at RM 9W (National Lead/Magnus Smelter), and at RM 11.6W (RiverTec Property). Steel mills are or were located at RM 2.4E (Evraz, aka Oregon Steel Mill) and at RM 8.3W (former Oregon Steel Mill operation at Front Ave LP). COIs associated with these types of operations include metals, TPH, PCBs, and PAHs. PCBs were a component of hydraulic fluid for high temperature applications (machining and die casting) where fire resistance was important, and were also a component of heat transfer fluid used in applications like heat exchangers and recirculating cooling systems.
- **Commodities Maritime Shipping and Associated Marine Operations.** In addition to the Port of Portland's large presence in Portland Harbor with three deep-water terminals committed to import/export, currently there are or have been several other commodity shipping facilities in the harbor (Map 3.2-11). These include the grain handling operations at CDL Pacific Grain (RM 11.4E) and Centennial Mills (RM 11.3W), edible oils at the former Premier Edible Oils facility (RM 3.6E), scrap metal export at International Terminals (RM 3.7E), cement import and distribution at Glacier NW (RM 11.3E), anhydrous ammonia and solid and granular urea at JR Simplot in the South Rivergate Industrial Park (RM 3E), and alumina, electrode binder pitch, and grain at the former Goldendale Aluminum property (RM 10E). Supporting maritime activities include over-water tug and barge moorage, maintenance and repair facilities, overwater bunkering and lightering, tug-assisted and independent maneuvering of vessels in and around marine facilities, and stevedoring (loading and discharging) product at vessels. Incidental spills into the river from commodities maritime shipping include organic materials, VOCs, PAHs, and TPH.
- **Rail Yards.** -the Study Area has hosted several types of rail yard and freight car repair operations. Active facilities are located at approximately RM 9.8 to 11.1E (UPRR Albina Yard), RM 8.6 to 9.5W (PTRR Guilds Lake Yard), and RM 4.8E (UPRR – St. Johns Tank Farm). Historical rail yard operations were located at and around RM 11.6W (BNSF Hoyt Street Railyard, and UPRR Union Station operations). Historical rail car maintenance operations were

located at RM 3.6 (ACF Industries). At rail yards used for fueling or rail car maintenance, COIs may include VOCs, SVOCs, TPH, PCBs, and metals. Railcar switching yards (RM 8.1W BNSF Willbridge Switching Yard) are locations where trains are assembled and disassembled, and this moving of railcars typically does not result in releases or produce waste streams.

COIs related to these facilities and operations reach the in-water Portland Harbor media through several migration pathways, including stormwater, industrial wastewater, overland flow, groundwater, bank erosion, and overwater releases. COIs associated with these pathways are typically related to site-specific operations, but in the case of shared stormwater conveyance systems, COIs may be associated with a number of facilities.

Commented [Int4]: This historical pathway discussion has been reinerted as it is a critical element of a CSM. It retention also preserves the balance between the historical and current pathway discussion.

Some contaminated surface soils exposed in the upland areas and along riverbanks can be carried directly to the river as riverbank erosion and in stormwater sheet runoff (i.e., overland transport). The greatest erosional events occur during high flows and floods. As development continued through the 1900s, the bank was armored in many areas. The occurrence and relative importance of riverbank contamination is not well characterized for all parts of the Study Area, but it is a focus of DEQ's Joint Source Control investigations. Contamination in riverbank soils can result from upland activities or from contaminated material used in construction fill activities. In some locations, contaminated dredged material may have been placed in low-lying areas subject to erosion.

While the quality of this fill material is generally undocumented, the time periods involved and the history of sediment contamination from a range of industrial and maritime sources suggest that contaminated sediment could have been included in the fill material. Bank erosion and overland transport of soil to the river were likely more important historically, prior to the development of extensive stormwater conveyance systems and paving of upland areas adjacent to the Study Area.

Migration of contaminants from upland areas to the river via the groundwater pathway is also a historical source of contamination to the river at a limited number of upland sites within the Study Area based on available information. At a subset of these sites, the historical groundwater pathway has contributed significant loading of upland contaminants to sediment and TZW. While some complete historical groundwater transport pathways have been mitigated or eliminated through source control actions, others remain complete, as identified in Section 10.1.3.2 below.

Historically, overwater releases were common occurrences for industries on the banks of the Willamette that relied on maritime shipping to get commodities to and from market. Overwater releases are likely important historical contributors to in-water contamination at sites that have long histories of overwater operations (e.g., ship building and repair, dock facilities, fuel facilities) and product transfers. However, prior to the relatively recent enactment of reporting requirements, overwater spills were generally undocumented.

Upstream sources also contributed to the historical contamination of the LWR. These sources included sewerage, stormwater runoff, and direct discharge of industrial wastes from upstream cities, towns, and industrial areas; agricultural runoff; and aerial deposition on the water surface and drainage areas within the Willamette Valley.

~~10.1.4.2~~10.1.3.2 Current

Many of the large historical operations in the harbor have ceased operating over the past 50 years. These former operations include widespread ship building and scrapping operations; large-scale chemical manufacturing; manufactured gas production and wood treatment; and the manufacturing, repair, and storage of PCB-containing electrical equipment. However, some historical operations continue to exist today, including bulk fuel storage, barge building, ship repair, automobile scrapping, recycling, steel manufacturing, cement manufacturing, transformer reconditioning, operation and repair of electrical transformers (including electrical substations), and many smaller industrial operations. Maps 3.2-3 through 3.2-12 show the locations of both current and historical major industrial operations in Portland Harbor.

Stormwater and wastewater discharges are regulated and permitted for many of the sites adjacent to the Study Area. However, sampling for RI-related chemicals in stormwater and catch basins only began in recent years and, for the most part, has only been done for those facilities that have voluntarily conducted a JSCS stormwater source control evaluation. In addition, under the 2003 Intergovernmental Agreement between DEQ and the City, the City is continuing through storm drain sampling to identify sites discharging RI-related chemicals to the Study Area. Significant examples of the City's work under its Portland Harbor Program are the identification of the GE Decommissioning and the Calbag-Nicolai sites as PCB sources to stormwater. Known or likely complete pathways for stormwater have been identified at many sites (see Section 4). As continued sampling is conducted under the JSCS and City programs, additional sites with known problematic stormwater discharges may be identified.

With the construction of stormwater treatment systems and wastewater treatment systems over the years, overland transport has been largely abated at most sites. A current overland transport pathway has been identified as likely complete at very few sites, although more such sites may continue to be discovered.

With respect to the groundwater pathway, available groundwater information for more than 120 upland sites bordering and/or in close proximity to the river was reviewed during the RI and under JSCS programs. Based on this data review, and on further sampling information collected and evaluated during the RI groundwater pathway assessment, current known complete or likely complete pathways have been identified for 11 sites, 51 sites have insufficient data to make a determination, and 58 sites have been identified as not having a complete pathway. The groundwater pathway assessment conducted during the RI developed detailed groundwater discharge and TZW sampling information at nine high priority sites. Based on these efforts, a current complete groundwater pathway with influence on TZW and sediment chemistry was confirmed at four sites, migration of groundwater was found to have no significant influence on TZW and sediment chemistry at four other sites, and the effect of upland groundwater on TZW and sediment chemistry could not be established at one site (see Appendix C2).

Riverbank erosion from contaminated and unstabilized bank areas may represent an ongoing release mechanism in the Study Area. Currently about 75 percent of the riverbanks within the Study Area are stabilized and armored with various materials, including seawalls, riprap, and engineered and non-engineered soil. Known or likely complete riverbank pathways have been identified at a few sites with unstabilized banks, although more such sites may continue to be discovered. The occurrence and relative importance of riverbank contamination is a focus of DEQ's JSCS investigations.

The activities most commonly associated with current overwater spills in the Study Area are product handling, overwater activities such as refueling, and spills from vessels. Overwater releases are likely important contributors to in-water contamination at sites that have long histories of overwater operations and product transfers. Spill records collected over the past approximately 30 years do not generally record large releases, but there have been some exceptions.

DEQ's JSCS program focuses on the abatement of current and threatened future releases of contaminants to the Study Area. The current status of that program is summarized in Section 4.6.

As with historical sources, current upriver sources also play a role in the contaminant distribution in the LWR. Current upstream loading is discussed in the following section.

~~10.1.5~~10.1.4 Loading, Fate and Transport

This section summarizes the information detailed in Section 6 of the RI on contaminant mass inputs (i.e., loads from external sources to the Study Area) and internal contaminant mass transfer mechanisms within the Study Area.

External loads include upstream loading via surface water and sediment bedload, stormwater, permitted industrial discharges, upland groundwater transport, atmospheric deposition, direct upland soil and riverbank erosion, groundwater advection through subsurface sediments, and overwater releases. Understanding ongoing sources and their associated contaminant loads to the Study Area is important in assessing recontamination potential, identifying the need for source control activities, and evaluating remedial technologies in the FS. Identification and control of current sources is being implemented by DEQ through the JSCS program. Many of these external loading terms have been quantified in this RI for the indicator contaminants

~~CSM ICs~~ ~~and~~ allowing ~~so~~ their relative magnitudes to~~can~~ be compared. These comparisons are presented in Section 10.2 for each indicator contaminant.

Upstream loading represents the largest current loading term for the Study Area. While upstream surface water and suspended sediment concentrations are typically lower than those measured in the Study Area, the very large flow volume of the river compared to the flow volumes for the other loading terms results in a relatively large mass load of contaminants compared to other current sources. This loading exceeds other source by 1 to 3 orders of magnitude for all of the CSM ICs, with the exception of total PAHs and TBT, for which mass loading estimates via groundwater advection through surface sediment are comparable with the mass input via surface water. Figure 10.1-3 shows estimated flow volumes used for the various loading terms.

Commented [Int5]: This figure should be retained, is important to understanding the relative load estimates presented in Section 10.2.

Current stormwater runoff is the second largest quantified annual external loading term to the Study Area for all indicator chemicals except total PAHs and arsenic (dioxins/furnas and TBT were not sampled in stormwater). The overall contribution of stormwater loading to the Study Area was likely more significant historically, prior to implementation of current management practices and stormwater runoff controls. Loading from CSO discharges is also a factor in stormwater loading, however, at a much reduced rate than in the past.

Stormwater is a migration pathway for contaminants in upland areas to reach the river via runoff from the local watershed. Contaminants present in stormwater runoff may be present in the upland watershed as a result of upland soil contamination, atmospheric deposition, and a wide range of anthropogenic activities. Stormwater-related chemicals are transported mostly via conveyance systems and discharged through numerous outfalls along the river shoreline within the Study Area. Overland flow of stormwater to the river also occurs in some relatively limited areas.

The other external loading mechanisms (permitted discharges, groundwater transport, atmospheric deposition, direct upland soil and riverbank erosion, groundwater advection through subsurface sediments, and overwater releases) are generally lower in magnitude than the upstream and stormwater loading. Where notable, the other mechanis~~n~~ms are discussed on a contaminant-specific basis in Section 10.2

Internal transfer mechanisms involve the transport of contaminant mass from one media to another within the Study Area, but do not add new contaminant mass to the Study Area. Internal fate and transport mechanisms include sediment resuspension, transport, and deposition, solid/aqueous-phase partitioning, abiotic/biotic transformation and degradation, biological uptake and depuration, and partitioning from surface sediment to surface water. Brief descriptions of important site processes and how they may affect contaminant distribution and site risks are presented below.

Commented [Int6]: This sentence was retained in EPA's July RL/SO, it has been moved here to the internal transfer mechanism subsection.

The transport, degradability, and bioavailability of a contaminant often relates to its tendency to associate with particulate material within the system. Many of the Portland Harbor contaminants are hydrophobic organic compounds, which tend to partition preferentially to the dissolved and particulate organic matter associated with the solid and aqueous phases of surface water, sediments, and pore water. Because the particulate organic matter within the solid phase of sediments represents the largest available pool of organic carbon in the Study Area, contaminated sediments represent the largest repository (by mass) of contaminants in the system.

The flow of river water is the primary mechanism for transport of both particle-bound and dissolved contamtaminants. Lateral and vertical movement of chemicals in surface water occurs primarily as a result of turbulent (eddy) dispersion (mechanical mixing). Higher flow velocities typically cause greater mixing and increased transport of suspended and bedload sediments. As described in Section 3, with the exception of the channel environment upstream of RM 10 and between RM 5 and 7, the Study Area appears to be a depositional or relatively stable sedimentary environment.

Relevant processes that influence sediment transport include deposition, erosion/resuspension, mixed-layer turbation, long-term burial, and ingestion/uptake by biota. The relative significance of these transport and fate mechanisms varies by contaminant, depending on source locations and the chemical-specific other physical/chemical properties. A potentially important mass transfer mechanism is surface sediment resuspension and movement of contaminants from bedded sediment to the water column with a resultant increase in mobility and bioavailability.

A variety of abiotic and biotic (microbially mediated) degradation processes are relevant for transformation and degradation of contaminants in the Study Area. The relevant processes vary by chemical and location. Relevant abiotic degradation/transformation/loss mechanisms include abiotic oxidation/reduction, hydrolysis, dehalogenation, volatilization (primarily from dissolved phase in surface water), and photolysis (primarily in upper levels of surface water). Microbially mediated degradation (biodegradation) involves the metabolic oxidation or reduction of organic compounds and is carried out predominantly by bacteria in aqueous environments, but yeasts and fungi may also contribute to biodegradation. Biodegradation can proceed to full mineralization of the compound, with end products of carbon dioxide and water, or an intermediate compound may be formed that is not easily biodegraded further.

Finally, a number of processes govern how organisms living in the Study Area are exposed to contaminants and how contaminants are transformed, excreted, or stored in tissue. Organisms living in the Study Area may take up (bioaccumulate) contaminants through physical (e.g., diffusion), chemical, and biological processes, including transfer of water-borne contaminants across gill structures or other tissues, consumption of prey, or ingestion of sediment. Organisms can modify the contaminant burden in their tissues through growth, reproduction, excretion, metabolic transformation, or sequestration. Some contaminants are transferred among organisms through trophic interactions. For some contaminants, tissue concentrations may increase (biomagnify) at progressively higher trophic levels in the food chain.

10.1.5 Site Receptors, Pathways, and Risk

Commented [Int7]: The summaries of the risk assements are important to provide the overall context and discussion of expousure sceanios and and assumptions.

The following subsections briefly summarize the major findings of the BHHRA (Section 8 and Appendix F) and BERA (Section 9 and Appendix G), including summaries of human use and ecology of the LWR.

10.1.5.1 Site Use and Human Health Risk Assessment Findings

Information on human uses of the river, its shorelines, and resources, as detailed in Section 3.2.5, was used to determine potential receptor populations for the BHHRA. Figure 8.2-1, the BHHRA CSM, lists the human receptor populations.

People interact with the river in a number of ways. Portland Harbor is a major industrial water corridor and working harbor, and the majority of the Study Area waterfront is currently zoned for industrial land use (City of Portland 2006b).

The Study Area also contains some natural areas and provides recreational opportunities, both on the water and along the riverbanks, including boat ramps, beaches, and waterfront parks. Recreational fishing is conducted throughout the LWR basin and in the Study Area, both by boaters and from shore. The extent to which commercial fishing occurs within the Study Area is not known, but it is presumed to be negligible. For Native American anglers, the Willamette River provides a ceremonial and subsistence fishery for Pacific lamprey and spring Chinook salmon. There is also documented evidence of transients camping along the river for extended periods of time.

Based on this site use information, the following potentially complete exposure pathways were quantitatively evaluated in the BHHRA:

- Incidental ingestion of and dermal contact with beach sediment
- Incidental ingestion of and dermal contact with in-water sediment
- Incidental ingestion of and dermal contact with surface water
- Incidental ingestion of and dermal contact with surface water from seeps
- Consumption of fish and shellfish
- Infant consumption of human milk.

The primary exposure pathway accounting for the majority of risk for human health in Portland Harbor is ingestion of fish. PCBs are the primary contributor to risk for fish consumption, and dioxins are a secondary risk contributor for fish consumption of both whole body and fillet tissue diets. PCBs and dioxins/furans both resulted in cancer risks greater than 1 x 10^{-4} and HQs greater than 1 for fish ingestion for both localized and Study Area-wide exposures. PCBs and dioxins/furans contribute approximately 98 percent of the cumulative cancer risk for whole-body fish ingestion and approximately 99 percent of the cumulative cancer risk for fillet fish ingestion on a Study Area-wide basis. The contribution of various contaminants to the cumulative cancer risks varies on a localized basis. Other indicator contaminants that resulted in cancer risks greater than 1 x 10^{-4} or HQs greater than 1 on a limited spatial scale and/or for a specific exposure scenario included cPAHs, DDx, BEHP, arsenic, and zinc.

10.1.5.2 Site Ecology and Baseline Ecological Risk Assessment Findings

Details on the Study Area's ecology, provided in the BERA (Appendix G and summarized in Section 9) and Section 3.1.6, are summarized here, followed by a summary of the findings of the BERA.

The majority of the Study Area is industrialized, with modified shoreline and nearshore areas (e.g., wharfs, piers extending out toward the channel, bulkheads, and riprap-armored banks). The federal navigation channel, authorized to –43 ft and currently maintained to –40 ft CRD, has less habitat diversity than the nearshore areas, but this is consistent with river systems generally. Some segments of the Study Area are more complex, with small embayments, shallow water areas, gently sloped beaches, localized small wood accumulations, and less shoreline development, providing some habitat for a suite of local fauna. Riparian, shallow-water, and vegetated habitats are limited to the nearshore area or shoreline, and are much less extensive.

The organisms that use the LWR include invertebrates, fishes, birds, mammals, amphibians, reptiles, and aquatic plants. Each group contributes to the ecological function of the river based on trophic level, abundance, biomass, and interaction with the physical-chemical environment and other species.

- Riverine invertebrates are predominantly benthic, living on or in such substrates as fine-grained sediments, gravel and cobble, plant roots, or large woody debris.

- The LWR is an important migration corridor for anadromous fish, such as salmon and lamprey, and provides habitat for numerous resident fish species (more than 40 species have been collected in many historical and recent studies) that represent four feeding guilds: herbivores, invertivores (either from the water column or bottom habitats), piscivores, and detritivores. A number of species are omnivores and utilize multiple food types.

- Limited suitable habitat for amphibians and reptiles is present in the LWR. Amphibians prefer undisturbed, shallow-water areas with adjoining ephemeral wetlands and emergent vegetation.

- Habitat in the Study Area is limited for semi-aquatic mammals because of past human modification of riparian habitats. The upland environment near the LWR is primarily urban, with fragmented areas of riparian forest, wetlands, and associated upland forests.

- Mink and river otter, both semi-aquatic species, were evaluated in the BERA. The Study Area offers at least marginally suitable habitat, and both species have been collected nearby (Elliott et al. 1999; Henny et al. 1996).

- For birds, the fragmentation of habitat may not be as critical as for mammals. Numerous aquatic and shorebird species, such as cormorants and spotted sandpipers, use the habitats, where available, in the Study Area.

The following complete and significant exposure pathways were quantitatively evaluated in the BERA using multiple lines of evidence:

- **Benthic invertebrates** – Direct contact with sediment and surface water, ingestion of biota and sediment, and direct contact with shallow TZW
- **Fish** – Direct contact with surface water, direct contact with sediment (for benthic fish receptors), ingestion of biota, incidental ingestion of sediment, and direct contact with shallow TZW (for benthic fish receptors)
- **Birds and mammals** – Ingestion of biota and incidental ingestion of sediment
- **Amphibians and aquatic plants** – Direct contact with surface water and shallow TZW.

In total, 89 contaminants (as individual chemicals, intermediate sums, or totals) were identified as posing potentially unacceptable ecological risks, including metals, TBT, PAHs and other SVOCs), PCBs, dioxins and furans, DDx and other pesticides, and VOCs. The following are key findings:

- PCB: HQs ≥ 1 occurred throughout the Study Area for river otter, mink, spotted sandpiper, bald eagle, and osprey, indicating possible population-level effects. The adverse effects in fish is low based on limited extent and frequency of TRV exceedances and the likelihood that uncertainties contribute to overestimates of risks.

- The combined toxicity of dioxins/furans and dioxin-like PCBs expressed as TEQ poses risk of reduced reproductive success in mink, river otter, sandpiper, bald eagle, and osprey.

- PCBs are responsible for the majority of total TEQ exposure, but the dioxin/furan TEQ also exceeds its TRV in some locations of the Study Area.

- Total DDx HQs ≥ 1 occurred for sculpin for certain LOEs and for spotted sandpiper. The weight of evidence indicates the DDx likely poses negligible risk to populations of these receptors because of the low magnitude and limited frequency of exceedances and likelihood that uncertainties contribute to overestimates of risks

The BERA found potentially unacceptable benthic risks in about 7 percent of the Study Area based on all lines of evidence. The contaminants in sediment that pose potentially unacceptable risk to the benthic community or populations are PAHs, PCBs, and DDx compounds. The phenolic compound 4-methylphenol may also be contributing to unacceptable benthic community risk.